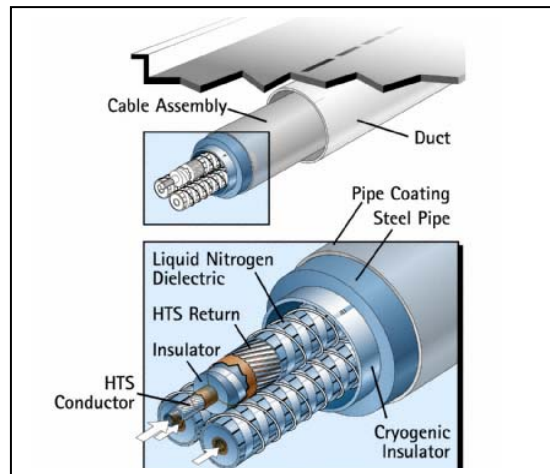


Superconducting Power Technology

Technology Description

Superconducting power technology refers to electric power equipment and devices that use superconducting wires and coils. High Temperature Superconductivity (HTS) enables electricity generation, delivery, and end use without the resistance losses encountered in conventional wires made from copper or aluminum. HTS wires currently carry 3 to 5 times the power, without the resistance losses of comparable diameter copper wires. HTS power equipment, such as motors, generators, and transformers, has the potential to be half the size and weight of conventional alternatives with the same power rating and only half the energy losses.



Source: American Superconductor

System Concepts

- HTS systems will be smaller, more efficient, and carry more power than a similarly rated conventional system.
- HTS systems will help the transmission and distribution system by allowing for greater power transfer capability, increased flexibility, and increased power reliability.

Representative Technologies

Transmission Cables
Motors
Generators

Current Limiters
Transformers
Flywheel Electricity Systems

Technology Applications

- Superconducting technology will modernize the electric grid and infrastructure, resulting in greater flexibility, efficiency, and cost effectiveness.
- Wire and Coils have reached a sufficient level of development to allow for their introduction into prototype applications of HTS systems such as motors, generators, transmission cables, current limiters, and transformers.
- Motors rated greater than 1,000 hp will primarily be used for pump and fan drives for utility and industrial markets.
- Current controllers will perform as a fast sub-cycle breaker when installed at strategic locations in the transmission and distribution system.
- Flywheel electricity systems can be applied to increase electric-utility efficiency in two areas—electric-load leveling and uninterruptible power systems (UPS) applications.
- Transformers are environmentally friendly and oil-free, making them particularly useful where transformers previously could not be sited, such as in high-density urban areas or inside buildings.
- Reciprocating Magnetic Separators can be used in the industrial processing of ores, waste solids, and waste gases, as well as performing isotope separations and water treatment.

Current Status

- Much of the research and development in HTS is focused on wire and system development and prototype system design and deployment.
- There are 18 manufacturers, eight National Laboratories, six utilities, and 17 universities participating in the U.S. Department of Energy Superconductivity Program alone. The list of manufacturers includes:

3M	ABB
American Superconductor	Pirelli Cables North America
IGC SuperPower	Waukesha Electric Systems
Southwire Company	

- Prototype power transmission cables have been developed and are being tested by two teams led by Pirelli Cable Company and Southwire Company respectively.
- A 1,000-horsepower prototype motor was produced and tested by Rockwell Automation/Reliance Electric Company. The results of these tests are being used to design a 5,000 hp motor.
- A team led by General Electric has developed a design for a 100 MW generator.
- A 15 kV current controller was tested at a Southern California Edison substation in July 1999.
- The design of a 3 kW/10 kWh flywheel system has been completed. The superconducting bearings, motor/generator, and control system have been constructed and are undergoing extensive testing. A rotor construction is underway.
- The design of the reciprocating magnetic separator has been finalized, and components for the system have been procured and assembled. The test site has been prepared, and cryogenic testing has begun.
- Use of HTS lines results in a 30% reduction in total losses. Total ownership costs are about 20% lower than traditional lines. HTS lines are nonflammable and do not contain oil or any other pollutant.

Technology History

- In 1911, after technology allowed liquid helium to be produced, Dutch physicist Heike Kammerlingh Onnes found that at 4.2 K, the electrical resistance of mercury decreased to almost zero. This marked the first discovery of superconducting materials.
- Until 1986, superconductivity applications were highly limited due to the high cost of cooling to such low temperatures, which resulted in costs higher than the benefits of using the new technology.
- In 1986, two IBM scientists, J. George Bednorz and Karl Müller achieved superconductivity on lanthanum copper oxides doped with barium or strontium at temperatures as high as 38 K.
- In 1987, the compound $Y_1Ba_2Cu_3O_7$ (YBCO) was given considerable attention, as it possessed the highest critical temperature at that time, at 93 K. In the following years, other copper oxide variations were found, such as bismuth lead strontium calcium copper oxide (110 K), and thallium barium calcium copper oxide (125 K).
- In 1990, the first (dc) HTS motor was demonstrated.
- In 1992, a 1-meter-long HTS cable was demonstrated.
- By 1996, a 200-horsepower HTS motor was tested and exceeded its design goals by 60%.
- A Pirelli Cable team installed a 120m HTS cable in Detroit, Michigan under the DOE Superconductivity Partnership Initiative. Since February 2000, Southwire's 30m prototype cable has been powering three manufacturing plants in Carrollton, Georgia.
- The first HTS cable, worldwide, to power industrial plants exceeded 13,000 hours of trouble-free service recently. The 30m cable was installed in Carrollton, Georgia, in June 2001. The cable has been unattended since then.

- HTS transformers have seen increased interest, as Waukesha Electric Systems demonstrated a 1-MVA prototype transformer in 1999. This team is also leading the development of a 5/10-MVA, 26.4-kV/4.2-kV three-phase prototype.
- A 750 kW HTS motor was demonstrated by Rockwell Automation in 2000. This team is now designing a motor with five times the rating.

Technology Future

Year of 50% Market Penetration

Motors	Transformers	Generators	Underground Cable
2018	2015	2019	2013

Source: ORNL - High Temperature Superconductivity: The Products and Their Benefits, 2002 Edition, Table ES-1.

- Low-cost, high-performance YBCO Coated Conductors will be available in 2005 in kilometer lengths.
- HTS wires will have 100 times the capacity of conventional wires.
- Payback periods will be within 2-5 years of operation.
- The present cost of BSCCO type HTS wire is \$200/kA-m. By 2005, for applications in liquid nitrogen, the wire cost will be less than \$50/kA-m; and for applications requiring cooling to temperatures of 20-60 K, the cost will be less than \$30/kA-m.

By 2010, the cost-performance ratio will have improved by at least a factor of four. The cost target is \$10/kA-m.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term.* DOE/PI-0002. November 2003.

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Market Data

Projected Market for HTS devices (Thousands of Dollars)	Source: <i>Oak Ridge National Laboratory - High Temperature Superconductivity: The Products and Their Benefits</i> , 2002 Edition, Total Market Benefits, p 40.								
	2004	2006	2008	2010	2012	2014	2016	2018	2020
Motors	0	0	27.29	169.24	527.03	1310.49	3103.37	6360.31	11322.83
Transformers	0	3.8	14.22	37.47	90.63	197.73	371.87	605.23	877.71
Generators	0	0	0	4.09	15.56	41.12	101.16	224.26	426.61
Cables	0	0.17	0.59	1.44	2.81	4.86	7.7	11.21	15.17
Total	0	3.97	42.1	212.24	636.03	1554.2	3584.1	7201.01	12642.32

The report assumes electrical generation and equipment market growth averaging 2.5% per year through 2020. This number was chosen based on historic figures (the past fifteen years) and the assumption that electric demand will drive electric supply.

Underground Power Cables: Market Penetration and Benefits	Source: <i>Oak Ridge National Laboratory - High Temperature Superconductivity: The Products and Their Benefits</i> , 2002 Edition, Total Market Benefits, p 40.								
	2004	2006	2008	2010	2012	2014	2016	2018	2020
% Market	0	6.7	15	27	40	56	69	77	80
Miles Sold this Year	0	13.89	32.68	61.77	96.19	141.47	183.15	214.73	234.35
Total Miles Installed	0	20.76	74.69	183.34	356.96	616.74	963.04	1379.11	1839.26
Total Annual Savings (10 ⁶ \$)	0	0.17	0.59	1.44	2.81	4.86	7.7	11.21	15.17

Technology Performance

HTS Energy Savings (GWh)	Source: <i>Oak Ridge National Laboratory - High Temperature Superconductivity: The Products and Their Benefits</i> , 2002 Edition, Tables M-2, T-1, G-1, C-2								
	2004	2006	2008	2010	2012	2014	2016	2018	2020
Motors	0	0	0.4	3	8	21	48	98	172
Transformers	0	0.1	0.2	1	1	3	6	9	14
Generators	0	0	0	0.1	0.2	1	2	3	6
Cables	0	3	18	56	133	270	488	806	1,236
Total	0	4	19	60	143	294	544	916	1,428